VALIDATION AND EXPANSION OF DISPRE2 QUANTITY-DISTANCE MODEL

by

Patricia Moseley Bowles
Southwest Research Institute
P.O. Drawer 28510
San Antonio, Texas 78228-0510

Twenty-seventh DOD Explosives Safety Seminar
Sahara Hotel and Casino, Las Vegas, NV
20-22 August 1996

ABSTRACT

The DISPRE2 model has been developed by Southwest Research Institute (SwRI) to predict the hazardous debris density and air blast at any given distance following an accidental detonation in an arch-shaped or rectangular above-ground ammunition magazine storing up to 5,000 kg of TNT equivalent explosives material. DISPRE2 is a self-contained software package, including pre- and post processors designed to run in a Windows environment on a personal computer. Version 1.0 of DISPRE2 was completed in October 1994 for the Klotz Club, an informal working group composed of delegates from eight countries with common concerns in safe explosives storage. This version of the software was introduced at the 1994 DOD Explosives Safety Seminar. The software is based on empirical procedures determined by the analysis of data accumulated by organizations other than SwRI and first principles calculations. Since submittal of Version 1.0, further validation of the model with all available test data has been accomplished. Version 2.0 of the software is now in the beta testing phase. SwRI has included in Version 2.0 the capability of analyzing non-earth covered magazines as well as the earth covered magazines treated by Version 1.0. One other addition to Version 2.0 is the capability of running the original DISPRE model (developed by SwRI for DOE and DDESB) as a separate run stream within the software using the procedures described in DDESB Technical Paper No. 13. The further validation of DISPRE2, the new features added to Version 2.0, and future planned expansion of the model are summarized in this paper.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**
4. TITLE AND SUBTITLE **Validation and Expansion of Dispre2 Quantity-Distance Model**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Southwest Research Institute, ,P.O. Drawer 28510,San Antonio,TX,78228-0510**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**16**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1.0 INTRODUCTION

The DISPRE2 model, developed by Southwest Research Institute (SwRI), is a tool which can be used to predict the hazardous debris density and air blast at any given distance following an accidental detonation in an arch-shaped or rectangular above-ground ammunition magazine storing up to 5,000 kg of TNT equivalent explosives material (Reference 1). Version 1.0 of the self-contained DISPRE2 software, designed to run in a Windows environment on a personal computer, was introduced at the twenty-sixth DOD Explosives Safety Seminar in 1994 (Reference 2). That model and subsequent versions to be discussed in this paper have been developed for the Klotz Club, an informal working group composed of delegates from eight countries with common concerns in safe explosives storage. The software is based on empirical procedures determined by the analysis of data from tests of aircraft shelters and other magazines and on first principles calculations. Since submittal of Version 1.0, further validation of the model with all available test data has been accomplished. Version 2.0 of the software (Reference 3) is now in the beta testing phase. SwRI has included in Version 2.0 the capability of analyzing non-earth covered magazines as well as the earth covered magazines treated by Version 1.0. One other addition to Version 2.0 is the capability of running the original DISPRE model (developed by SwRI for the U.S. Department of Energy [DOE] and DDESB) as a separate run stream within the software using the procedures described in DDESB Technical Paper No. 13 (Reference 4). The new features added to DISPRE2 Version 2.0, the further validation of the model, and future planned expansion are summarized in this paper.

2.0 SOFTWARE MODIFICATIONS AND NEW FEATURES

Modifications to DISPRE2 in Version 2.0 can be considered in four main categories: (1) incorporation of the original DISPRE model as an option, (2) expansion of the model to include non-earth covered magazines, (3) changes to the procedures used for earth covered magazines in Version 1.0, and (4) correction of programming errors discovered during further validation work. The modifications accomplished for each of these categories are discussed in this section.

2.1 Incorporation of DISPRE Model as Option in DISPRE2

DISPRE2 Version 2.0 has been modified to add the original DISPRE model (Reference 5) to the expanded procedures for analyzing earth and non-earth covered ammunition magazines. The DISPRE option is intended for analysis of non-earth covered, rectangular explosives processing or handling buildings containing no more than 120 kg of explosives at any given time. The DISPRE procedures have been incorporated as they are represented in DDESB Technical Paper No. 13 (Reference 4). No modifications were made to the steps described in that paper. SwRl had to develop new FORTRAN modules for all steps, including decision-making within the software. A separate path, or run stream, had to be created in DISPRE2 to incorporate these new modules and control the execution of the DISPRE option of the overall software. Significant changes to input for this path were necessary since DISPRE is structured on a component analysis basis, whereas DISPRE2 is directed more toward analyzing a structure as a whole.

The new DISPRE run stream has been tested and debugged along with the rest of DISPRE2 Version 2.0. It was subjected to testing against data cases used in the development and validation of the original (manual step-by-step procedure) DISPRE model. Comparable results (not always identical due to arithmetic round off) are obtained between DISPRE2 Version 2.0 and the manual procedure. The only exception to this is with high velocity debris (near the 305 m/sec limit for the DISPRE model). Correction of an error discovered in the MUDEMIMP code has caused a reduction in predicted distance for some cases involving these high velocity debris. A specific case in point is debris from the clay tile wall in

example problem number 3 in Reference 4. The corrected error involves the angle increment used in stepping through a debris trajectory and using the correct distance at which a piece of debris hit the ground (even if it impacts between increments). The predicted distances for these debris now compare more favorably with data.

2.2 Inclusion of Non-earth Covered Magazines

The DISPRE2 model was expanded to include non-earth covered magazines using the same basic three step approach used to predict hazardous debris distances from aircraft shelters and the headwalls of earth covered magazines. First, the blast loads are calculated on the walls and roof of the non-earth covered magazine. These loads and material property and geometry information for the structure are used to define "breakup" parameters necessary for debris dispersion calculations (i.e., probability density functions describing debris velocities, masses, launch angles, etc.). A Monte-Carlo based dispersion code then determines debris throw distances for a representative number of debris and calculates debris areal densities. One-fourth of the roof debris and all debris from the wall facing a given direction are included in the debris densities calculated in each direction from the magazine. The effects of a berm or standard barricade in front of any of the magazine walls can be considered in the debris density calculations.

Some simplifying assumptions were made in order to include non-earth covered magazines in Version 2.0 of DISPRE2. This latest version of the code is only intended to analyze debris dispersion from rectangular concrete magazines assuming that debris is thrown from all the walls and roof, even for very small loading densities. Non-rectangular magazines can be analyzed as "equivalent" rectangles, although the reduction in accuracy caused by this approximation is not known. The maximum charge weight limit of 5,000 kg, which applies generally to all magazines analyzed with DISPRE2, is also applicable for non-earth covered magazines. A more accurate, less conservative approach for very small charge weights may be developed in the future, and the procedure may be expanded to include non-earth covered arch magazines. Finally, one quarter of the roof debris is assumed to be thrown in each of the four directions out the sides of the magazine, regardless of the roof geometry or the charge placement. All roofs are assumed to be nearly flat so that the mean launch angle for roof debris is vertical to the ground surface. Further details of the three step procedure and the calculation of hazardous debris distances are provided in Reference 6.

2.3 Modifications for Analysis of Earth Covered Magazines

No modifications were made to the procedures used to calculate hazardous debris distances around aircraft shelters. The approach used in Version 2.0 of DISPRE2 to calculate debris densities out the front of earth covered ammunition storage magazines from headwall debris has been slightly modified to be consistent with the approach used for non-earth covered magazines. Since the front wall, or headwall, of an earth covered magazine is very similar to a typical wall of a non-earth covered magazine, the DISPRE2 model uses the same basic assumptions to calculate debris densities for both cases. The previous approach in DISPRE2 Version 1.0 for calculating total debris mass, and the area over which debris are assumed to be distributed for areal density calculations, has been changed so that now the total debris mass is assumed equal to the mass of the entire front wall. These debris are assumed to be distributed over a triangular ground area defined by a total sector angle of 20 degrees.

The procedures used in DISPRE2 to determine hazardous distances for very low loading densities around aircraft shelters and earth covered magazines have been reviewed and extended to include non-earth covered magazines. At very low loading densities, little or no debris will be thrown from explosive magazines. The specific limit loading densities used in the DISPRE2 model to determine where no

hazardous debris are thrown depend on the type of magazine and the presence of a barricade. Table 1 summarizes the assumed lower limit loading densities causing no debris threat in DISPRE2. As shown in the table, it is conservatively assumed that there is no lower limit for zero debris threat for non-earth covered walls of conventional magazines except when they face a barricade. The criteria for zero debris for aircraft shelters are explained in Reference 1.

Table 1. Criteria Used at Low Loading Density by DISPRE2 Version 2.0

Magazine Type	Direction	Criteria Used at Low Loading Densities (Q/V) (kg/m^3)	
		With Barricade	**Without Barricade**
Earth Covered Magazines	Front	Calculated hazardous distance reduced to zero between Q/V = 0.08 and Q/V = 0.02	No lower limit Q/V for zero debris threat
	Side/Back	No lower limit Q/V for zero debris threat	Hazardous distance set to zero when Q/V < 0.04
	Doors	Door distance included in hazardous debris distance calculated to Side/Back	No lower limit Q/V for zero debris threat
Non-Earth Covered Magazines	All Directions	Calculated hazardous distance reduced to zero between Q/V = 0.08 and Q/V = 0.02	No lower limit Q/V for zero debris threat
	Doors	No lower limit Q/V for zero debris threat, but doors redirected by barricade	No lower limit Q/V for zero debris threat
Aircraft Shelters	All Directions	Not considered in DISPRE2	Total debris mass reduces to zero (no hazardous debris) at Q/V = 0.04
	Doors	Not considered in DISPRE2	No door debris when calculated initial velocity is less than values shown in Figure 4.9 or Reference 1

The data and logic used to establish the cutoff loading density for the earth covered sides of conventional magazines and doors is also discussed in Reference 1, except the case where the magazine doors face a barricade. In these cases, a limited comparison to data shows that the empirical equation used to predict the hazardous debris distance for soil and debris thrown out the sides of earth covered magazines provides a reasonable estimate of the measured door distance redirected out the sides of magazines with barricaded headwalls in tests at low loading densities. This also helps account for redirected headwall debris. Since these redirected debris will control hazardous debris distances out the sides at very low loading densities when no debris are created from the earth covered sides of the magazine, no limit loading density for zero debris is applied out the sides of earth covered magazines facing a barricade.

The method used to calculate hazardous debris distance out the front of magazines facing a barricade has also been modified in Version 2.0 for very low loading densities. A reduction factor is now used for loading densities less than 0.08 kg/m^3 in order to match data measured at very low loading densities. Limited data suggest that barricades are very effective at containing headwall debris for low

loading densities. Since DISPRE2 does not explicitly model debris impact with the barricade, this effect is modeled by applying a reduction factor which linearly reduces the calculated hazardous debris distance from its full value at a loading density of 0.08 kg/m^3 to zero at 0.02 kg/m^3. This incorporates the basic observed trend where the barricade largely contains hazardous debris at these loading densities.

2.4 Programming Errors Corrected in DISPRE2 Version 2.0

Several computer programming errors were discovered in DISPRE2 Version 1.0 and corrected in DISPRE2 Version 2.0. Some of these corrections are notable because they cause calculated values to agree more closely with measured values than reported in Reference 1. First, an error was discovered in the coding which calculates the impulse used to determine the maximum velocity of magazine and aircraft shelter doors. This error was corrected so that only the shock and quasistatic impulse up until the critical vent time is used to calculate the door initial velocity. At that point in time, the door has traveled far enough from the structure so that it is no longer accelerated by internal blast pressures. Previously, the entire calculated shock impulse, assuming an infinitely rigid structure, was used to calculate door velocity. Secondly, the coding used to calculate the initial velocity of debris from magazine headwalls has been corrected so that only the mass of the headwall, and not the overlying soil, is used as the mass per unit area (m) in the velocity calculation ($v = i/m$). This error caused calculated hazardous debris distances out the sides of earth covered magazines to be greater than those out the front for some loading densities in Version 1.0 of DISPRE2. It should be noted that other errors, mainly in the post processor, have been discovered and documented during the beta testing phase of Version 2.0. Correction of all documented errors is anticipated by October 1996 when a new version of the software will be submitted to the Klotz Club.

3.0 FURTHER VALIDATION OF SOFTWARE

Due to unanticipated problems in obtaining, using, and verifying the BLASTX computer code (Reference 7) which is an integral part of DISPRE2 (and for which SwRI was dependent on others to provide the Windows executable code and verifiable results), full validation of the model with all available test data and complete debugging were not possible for Version 1.0 of DISPRE2. Additional funding was provided by the Klotz Club to further validate the model and to incorporate necessary software modifications. The modifications are summarized in Section 2.0 of this paper. Validation of the model is discussed briefly in the remainder of this section.

3.1 Debris Densities Around Non-earth Covered Magazines

Figures 1 through 4 show examples of comparisons between debris areal densities predicted by DISPRE2 (in terms of grams of debris per square meter) and values measured in Swiss tests on one-tenth scale, one-story above ground magazines (Reference 8). The comparisons required use of a special version of the MUDEMIMP code which was identical to the version in DISPRE2 except that it also output non-cumulative debris densities in terms of debris weight based on the actual weights of each piece of debris modeled by the code. No debris roll was assumed in this comparison because debris were only collected in sand beds surrounded by a wooden frame. The experimenters assumed the wood frame trapped any debris landing in the beds and stopped any debris from rolling inside the beds. Sand beds were placed at specified distances out the back (90 degrees) and side (O degrees) of the magazines, and at a 45 degree angle between the back and side. The figures show comparisons between measured debris densities at one-tenth scale and predicted values at charge weights corresponding to full scale values between 200 kg (0.2 kg scaled charge weight) and 5,000 kg, which resulted in loading densities between 0.3 kg/m^3 and 7.5 kg/m^3 for the magazines. In general, the calculated debris densities match the

measured values well at the higher loading densities (Figures 1 and 2) while they tend to overpredict measured values at the lower loading densities (Figures 3 and 4). In both cases DISPRE2 tends to predict measured debris densities best at distances approaching the hazardous distance, where the one-tenth scale areal debris density is less than 20 g/m^2 (the average calculated debris mass was about 1 g so the hazardous density at one-tenth scale was less than 2 g/m^2).

3.2 Debris Density Distributions Around Aircraft Shelters

Comparisons have been made of cumulative hazardous debris density vs. distance relationships calculated with DISPRE2 to measured values from several aircraft shelter test series. Figure 5 compares densities out the side for the full scale HAS test (Reference 9). Figures 6 through 8 show comparisons between calculated values and debris densities measured out the front, rear, and side of the full scale aircraft shelter for Distant Runner Event 4 (Reference 10). These latter figures compare densities calculated with DISPRE2 based on 5 degree sector collection areas with densities determined from debris weighing more than 136 grams collected within 5 degree sectors in the Distant Runner tests. The 136 gram criteria is used as an approximate means of defining the smallest debris with a hazardous kinetic energy. The total debris mass calculated within the DISPRE2 code for use in the debris dispersion calculations is only intended to represent the expected amount of debris large enough to have a hazardous kinetic energy.

Figures 5 through 8 show a general trend where the DISPRE2 code underpredicts the measured density vs. distance relationship at low loading densities and overpredicts this relationship at higher loading densities. For example, Figure 5 shows that the measured densities are underpredicted for the HAS test (loading density equal 0.08 kg/m^3) , and Figures 6 through 8 show that the measured densities are underpredicted in some directions for the Distant Runner Event 4 test (loading density of 0.2 kg/m^3) . Other comparisons with higher loading densities indicated that the measured densities are overpredicted. Comparisons of total number of predicted and measured debris do not show this consistent trend. Therefore, this trend is due to the fact that debris distances are overpredicted by the DISPRE2 code to a greater extent as the loading density increases. This causes the cumulative densities to also be overpredicted to a greater extent since the density decreases much more slowly with distance when debris pass through the collection areas rather than stopping.

Comparisons of measured cumulative hazardous density (at one-third scale) vs. distance relationships for the one third scale PAS test series (Reference 11) show the same trend discussed above for the available full scale aircraft shelter tests. Comparisons for the PAS2 test, with a loading density of 0.06 kg/m^3 , and the PAS3 test (in some directions), with a loading density of 0.2 kg/m^3, compare very well or the measured values are underpredicted. Comparisons for the PAS4 and PAS5 tests, both with a loading density of 0.56 kg/m^3, indicate that the measured density vs. distance relationship is overpredicted by the DISPRE2 code. Figures 9 and 10 show plots of representative comparisons of calculated and measured debris densities for the PAS test series.

In summary, the comparison between the more general density vs. distance relationships follow the same trend as the specific comparison between measured and calculated hazardous ranges. The DISPRE2 code tends to overpredict measured distances by a factor between one and two except at low loading densities (less than 0.2 kg/m^3), where calculated distances compare more closely with measured values and may underpredict by 10% to 20%.

3.3 Hazardous Debris Distances Around Aircraft Shelters

Hazardous distances calculated with DISPRE2 Version 1.0 were compared to hazardous ranges measured in tests conducted on aircraft shelters at a number of different scales in Reference 1. These same comparisons have been repeated using DISPRE2 Version 2.0. Model predictions were compared to three full scale tests of third generation U.S. shelters (loading densities ranging from 0.08 kg/m^3 to 0.8 kg/m^3) and four scaled tests of Norwegian/U.S. shelters. The method used to include both comparisons on a single graph is discussed in Reference 1. The results for the new comparison using Version 2.0 are shown in Figure 11. As before with Version 1.0 of the software, the model still predicts hazardous debris density, and thus hazardous distance, reasonably well over a relatively wide range of loading densities. Since the 0.8 kg/m^3 loading density corresponds to an explosive weight of 4,160 kg, the loading densities shown in Figure 11 are representative of the full range of charge weights considered by the DISPRE2 model for aircraft shelters. Note that, although Figure 11 only shows comparisons of predicted to measured densities of 1 hazardous piece of debris per 55.7 m^2 for the arch, front, and rear directions, Figures 5-8 show the same trend. The door debris ratios plotted in Figure 11 are ratios of maximum predicted distance to maximum measured distance, as opposed to hazardous debris distance. The DISPRE2 Version 2.0 code tends to overpredict measured densities by a factor less than two except at low loading densities, where calculated distances can be underpredicted somewhat. The door distances are all conservatively overpredicted; however, the ratios are much closer to one than with DISPRE2 Version 1.0. Overall, Version 2.0 of the software demonstrates better comparisons between predicted and measured hazardous and maximum distances than Version 1.0.

3.4 Hazardous Debris Distances Out the Front of Earth Covered Magazines

As noted, the approach used in DISPRE2 to calculate debris densities out the front of earth covered magazines from headwall debris has been modified slightly to be consistent with the approach used for non-earth covered magazines. Also, an empirical reduction factor was incorporated into the model to account for the effect of standard barricades for loading densities less than 0.08 kg/m^3. Table 2 shows a comparison between measured and predicted hazardous distances for headwall debris from tests conducted at very low loading densities on magazines with barricades in front of the magazine headwalls. The table shows a comparison of hazardous densities measured out the front of the headwalls of full scale vintage World War II earth covered igloos tested during the Navajo and Hastings test series (References 12 and 13). The comparisons show that the DISPRE2 predictions of the full scale measured hazardous debris densities are generally conservative, but typically not overconservative. The calculated values include the effects of debris roll. However, the calculated value assuming no roll is also shown for the Navajo test conducted with 204 kg because there was 1 m high vegetation in the debris collection area, which would tend to reduce debris roll.

Table 2. Comparison of Calculated and Measured Hazardous Debris Distances out the Front of Earth Covered Magazines

Series	Charge Weight (kg)	Loading Density (kg/m^3)	Hazardous Distance (m)		Ratio of Predicted to Measured
			Predicted	Measured	
Hastings	68	0.22	270	190	1.42
Hastings	45	0.14	209	130	1.61
Hastings	36	0.12	181	160	1.13
Hastings	27	0.09	151	130	1.16
Hastings	18	0.06	70	40+	1.75
Hastings	5.4	0.02	0	0	1.00
Navajo	204	0.66	334	190	1.76
Navajo	68	0.22	169 (93*)	137	1.23 (0.68*)

* Calculated with no debris roll
\+ Single, large piece of debris

These igloos had a standard barricade in front of the headwall, but debris distances are not currently modified in DISPRE2 based on any consideration of low angle debris that is stopped by barricades or berms in front of a magazine. This is realistic for cases where high angle debris (i.e., debris with a high enough launch angle to clear the barricade) set the debris hazardous distances. Analyses conducted during this study indicate that, for loading densities less than about 0.2 to 0.5 kg/m^3, this is a realistic assumption. At higher loading densities, calculated debris throw distance for low angle debris, including calculated roll distances, tend to set the hazardous debris distances out the front of earth covered magazines. Therefore, it is possible that comparisons between hazardous distances calculated out the front of earth covered magazines with significantly higher loading densities than those shown in Table 2 would compare more conservatively to measured values.

3.5 Hazardous Debris Distances Out the Sides of Earth Covered Magazines

Hazardous debris distances out the sides of conventional earth covered magazines are calculated with an empirical formula for estimating the distance large soil clods are thrown from a shallow buried explosion as discussed in Reference 1. Distances calculated with this formula matched data from the Navajo test series (Reference 12) relatively well, as shown in Table 3. According to Reference 12, hazardous debris distances out the sides and back were set by debris from the vent stack, which was a 0.6 m square concrete tube that protruded 0.8 m above the soil cover. The earth cover rose about 20 m during tests with differing charge weights and settled with only minor scattering. The rear walls and side walls were recovered either in place, on the floor of the magazine, or on the earth cover. The empirical formula overpredicts debris throw distances at very low loading densities since the loads no longer resemble those from a buried explosive, and the strength of the magazine becomes important. The hazardous debris distance from the earth covered walls of magazines is set to zero at all loading densities less than or equal to 0.04 kg/m^3 in Version 1.0 of DISPRE2, as explained in Reference 1.

The same approach is used for Version 2.0 of the code except cases where a barricade in front of the magazine headwall redirects the magazine door towards the side of the magazine. Comparisons between the measured distance that the door is redirected out the side of the magazine at low loading densities and the hazardous distance calculated out the side with the empirical formula are shown in Table 3. Since the empirical equation provides a reasonable estimate of the measured distances, this method is used at very low loading densities (including those less than 0.04 kg/m^3) to account for the door throw distance out the side. Also, in the Hastings igloo tests (Reference 13), significant headwall debris throw distances (50 m to 100 m) are reported at angles outside the 90 degree sector in front of the headwall at loading densities as low as 0.09 kg/m^3. Use of the empirical formula at low loading densities also helps account for this type of debris.

Table 3. Comparison of Measured and Predicted Hazardous Debris Distances from Earth Covered Sides of Magazines with Low Loading Densities

Series	Charge Weight (kg)	Loading Density (kg/m^3)	Hazardous Distance (m)		Ratio of Predicted to Measured
			Predicted	Measured	
Navajo	68	0.22	84	69	1.22
Navajo	204	0.66	120	92	1.30
Hastings	27	0.09	72	Not Available	N/A
Hastings	36	0.12	77	Not Available	N/A
Hastings	45	0.15	82	Not Available	N/A
Hastings	27	0.09	72	Not Available	N/A
Hastings	18	0.06	64	Not Available	N/A
Hastings	11	0.04	56	30 (door)	1.87
Hastings	5.4	0.02	46	40 (door)*	1.15

* Average of 5 tests

4.0 FUTURE PLANNED EXPANSION OF DISPRE2

DISPRE2 Version 2.0 has the same constraints as discussed in Reference 1, except that the code can now also consider non-earth covered magazines with charge weights up to 5,000 kg and non-earth covered processing and handling buildings with charge weights up to 120 kg (the DISPRE procedure charge weight limit). Recommended improvements for the DISPRE2 model include the consideration of higher charge weights in magazines and, possibly, a more accurate consideration of the effects of berms and headwalls.

In an effort to determine necessary modifications to DISPRE2 to expand the model to treat high loading density situations, SwRI recently completed two sets of preliminary analyses for the Klotz Club (References 14 and 15). Three tests from a series of Swiss magazine tests (Reference 8), three of the Australian/UK magazine trials (References 16 - 18), and one "DEN" test (Reference 19) were examined

for the first set of analyses using DISPRE2 Version 2.0 with no significant adjustments. The second set of analyses includes seven more tests from Reference 8 and four additional tests from References 16 - 18. Since the loading densities of all these tests range from 7.3 to 62 kg/m^3, and full scale equivalent explosive quantities in each case are greater than or equal to 5,000 kg, all 18 test situations were beyond the intended and validated limits of the DISPRE2 Version 2.0 model. However, since the purpose of the analyses was to illustrate which portions of the model will require modifications in order to expand it, only minor adjustments, if any, were made to the DISPRE2 procedures. The deviations, when necessary, involved the selection of debris collection bin size to match collection areas used in the tests and, in some cases, the turning off of debris roll due to either the type of collection used or the presence of earth traverses around a structure.

In general, the DISPRE2 calculated debris densities conservatively overpredict measured debris densities for the Swiss and Australian/UK tests (References 14 and 15). The model predictions tend to match measured data best at distances approaching the hazardous distance (corresponding to one lethal fragment, with kinetic energy greater than 79 Joules, per 56 m^2). As part of the analyses, a couple of rough adjustments were made to the model to help indicate which areas require modification. For example, although it is certainly appropriate to consider part of the roof debris as landing in each direction around a structure, additional calculations with the roof debris excluded from the debris density showed a better match to the data. This suggests the initial debris launch characteristics, especially launch angle, will require some type of modification for high loading density situations. In the Swiss magazine tests, most of the roof debris seem to have been launched at very high angles, resulting in the debris landing back down on or very near the original magazine position. Current and proposed tests by the Ernst-Mach-Institut (EMI) will provide measurements of debris launch angles and velocities for use in expanding DISPRE2.

The total destroyed mass and the average debris mass will also require modification to account for probable pulverization of much of the magazine wall and roof. The preliminary calculations reported in References 14 and 15 suggest that the total effective destroyed mass used in the MUDEMIMP code within the model needs to be a reduced mass. Available mass data associated with the tests in References 8, 16, 17, and 18 and additional proposed tests will need to be studied to develop an appropriate representation of this mass reduction. Since a more reliable database is necessary, experiments are being proposed by EMI to collect all mass of a structure exposed to a detonation and to separate hazardous debris from small particles (lost mass).

The expansion of the DISPRE2 model to treat high loading situations in storage magazines requires examination of different loading realms than for magazines with low loading densities. At high loading situations, the fragmentation mechanism of concrete walls changes from typically gas pressure overloading at low loading situations to composite shock overloading (close-in loading). However, since there is such a large amount of explosives spread throughout a structure, the load can actually be a combination of composite shock overloading, blast impulsive overloading, and gas pressure overloading, each running on different time scales and pressure levels. It is, in short, a much more complex load to predict. A workgroup appointed by the Klotz Club to consider all aspects of the expansion process and propose steps necessary to attain an expanded model is proposing to take an empirical "shortcut" from the DISPRE2 procedure. Instead of correlating debris data to the internal load as is done in Version 2.0, it is proposed to directly determine the debris parameters as a function of loading density, scaled distance, and scaled wall thickness. A joint program by SwRI and EMI, including the conduct of experiments and tests and the utilization of these and existing data, has been proposed to the Klotz Club to expand DISPRE2 to treat high loading situations in storage magazines.

5.0 REFERENCES

1. Bowles, P.K., Oswald, C.J., and Polcyn, M.A., "Earth Covered Ammunition Magazines Quantity-Distance Model, DISPRE2", SwRI Project 06-5394, prepared for KLOTZ Club (France, Germany, Norway, Sweden, United Kingdom, Switzerland, United States), October 1994.

2. Bowles, P.M. and Oswald, C.J., "Earth Covered Ammunition Storage Magazines Quantity-Distance Model, DISPRE2", Twenty-Sixth DoD Explosives Safety Seminar Proceedings, Miami, FL, August 1994.

3. Bowles, P.K., Polcyn, M.A., Butts, D.G., and Sparks, P.L., "DISPRE2 User's Manual for Earth Covered Ammunition Magazines Quantity-Distance Model", SwRI Project 06-5394, prepared for Klotz Club (France, Germany, Norway, Sweden, United Kingdom, Switzerland, United States), May 1995.

4. "Prediction of Building Debris for Quantity-Distance Siting", Department of Defense Explosives Safety Board Technical Paper No. 13, April 1991.

5. Bowles, P.M., Oswald, C.J., Vargas, L.M., and Baker, W.E., "Building Debris Hazard Prediction Model", prepared for Bernard Johnson Incorporated under contract to Mason & Hanger-Silas Mason Co., Inc., Pantex Plant, Amarillo, TX, February 1991.

6. Bowles, P.K., Oswald, C.J., and Polcyn, M.A., "Earth Covered Ammunition Magazines Quantity-Distance Model, DISPRE2: Addendum", SwRI Project 06-5394, prepared for Klotz Club (France, Germany, Norway, Sweden, United Kingdom, Switzerland, United States), May 1995.

7. Britt, J.R., "Enhancements of the BLASTX Code for Blast and Thermal Propagation in Protective Structures: BLASTX Version 2.0", Science Applications International Corporation, prepared for U.S.A.E. Waterways Experiment Station, Contract DACA3992-C-0048, November 1992.

8. "Modellversuche Fiir Oberirdische Explosivstoffmagazine", Volumes I-III, Basler & Hofmann Ingenieure und Planer, Ziirich, Switzerland, B952-2, B952-3, B952-4, 1979.

9. Bultmann, E.H., Jr. and Austin, Bryan S., "Aircraft Shelter Upgrade Program (ASUP) GP Bomb/FAE/QD Tests-HAS-QD Event", New Mexico Engineering Research Institute, TheUniversity of New Mexico, Albuquerque, NM, prepared for Phillips Laboratory, Air Force Materiel Command, Kirtland Air Force Base, NM, November 1993.

10. Ward, J., DISTANT RUNNER--Debris Recovery and Analysis Program for Events 4 and 5", NSWC, White Oak, 28 April 1982.

11. Bultmann, E.H., Jr. and Schneider, B.A., "Norway/United States Design Protective Aircraft Shelter (PAS) Quantity-Distance Program 1/3-Scale Test Series", New Mexico Engineering Research Institute, The University of New Mexico, Albuquerque, NM, prepared for Phillips Laboratory, Air Force Materiel Command, Kirtland Air Force Base, NM, (PAS1-4 Volumes I-V), August 1993, (PAS5, Volumes I and II), January 1995.

12. Reeves, H.J., "Revised Quantity-Distance Criteria for Earth Covered Igloos", U.S. Army Ballistic Research Laboratory, Paper submitted to DDESB AC/258 Storage Sub-Group, 14 October 1980.

13. Reeves, H.J., and Robinson, W.T., "Hastings Igloo Hazards Tests for Small Explosive Weights", U.S. Army Ballistic Research Laboratory Paper Memorandum, Report ABRLMR-03356, May 1984.

14. Bowles, P.M., "Preliminary DISPRE2 High Loading Density Analyses", Final Letter Report, SwRI Project 06-7105, prepared for Norwegian Defence Construction Service/Klotz Club, July 27, 1995.

15. Bowles, P.M., "Additional DISPRE2 High Loading Density Analyses", Letter Report, SwRI Project 06-7105, prepared for Norwegian Defence Construction Service/Klotz Club, January 1996.

16. Bowman, F., Henderson, J., Rees, Dr. N.J.M., and Walker, J., "Joint Australian/UK Stack Fragmentation Trials, Phase 1 Report," D/Safety/11/55/22.

17. Henderson, J., Walker, J., Rees, Dr. N.J.M., and Bowe, R.A., "Joint Australian/UK Stack Fragmentation Trials, Phase 2 Report," D/Safety/11/55/22, August 1985.

18. Henderson, J., "Joint Australian/UK Stack Fragmentation Trials, Phase 3 Report," D/ESTC/14/1/8/2, ESTC/Report No. 3/90, November 1990.

19. Prasse, H.G., "Untersuchungen der Trümmer- und Splitterwirkung bei Explosionsereignissen in Munitionslagerhaeusern," Bundesamt für Wehrtechnik und Beschaffung, Koblenz, Ernst-Mach-Institut, E/K41P/A0137/A611, June 1983.

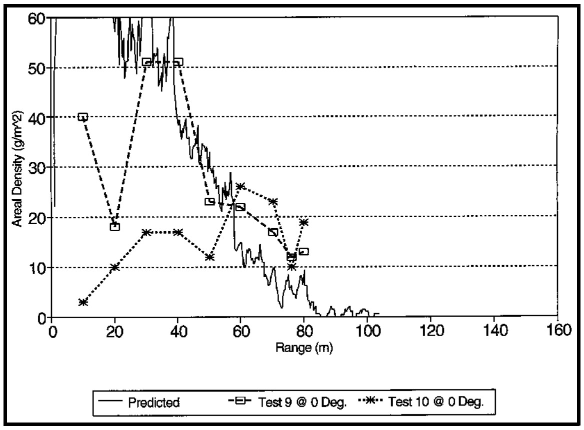

Figure 1. Comparison of Measured and Predicted Areal Debris Densities for Swiss Magazine Test with Loading Density of 7.5 kg/m^3 (5000 kg Full Scale Charge Weight)

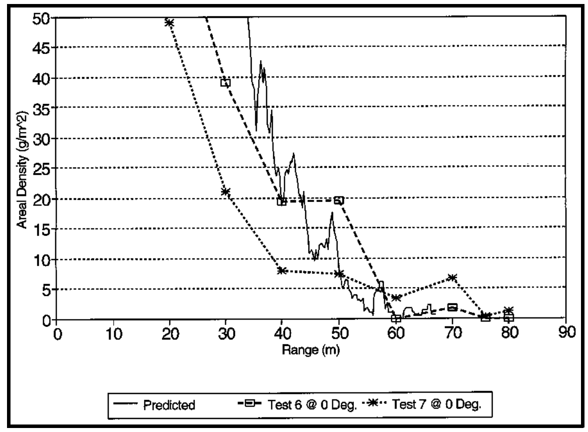

Figure 2. Comparison of Measured and Predicted Areal Debris Densities for Swiss Magazine Test with Loading Density of 1.5 kg/m^3 (Full Scale Charge Weight of 1000 kg)

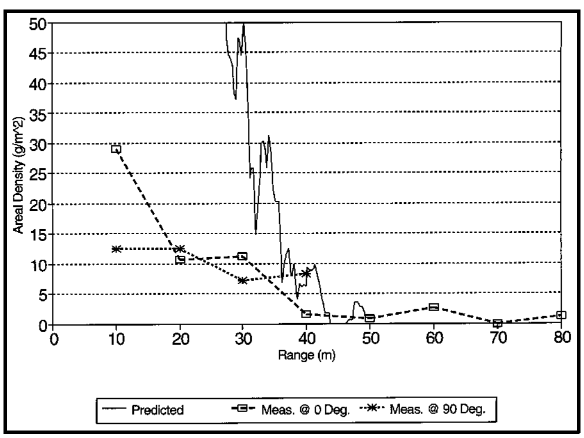

Figure 3. Comparison of Measured and Predicted Areal Debris Densities for Swiss Magazine Test with Loading Density of 0.75 kg/m^3 (Full Scale Charge Weight of 500 kg)

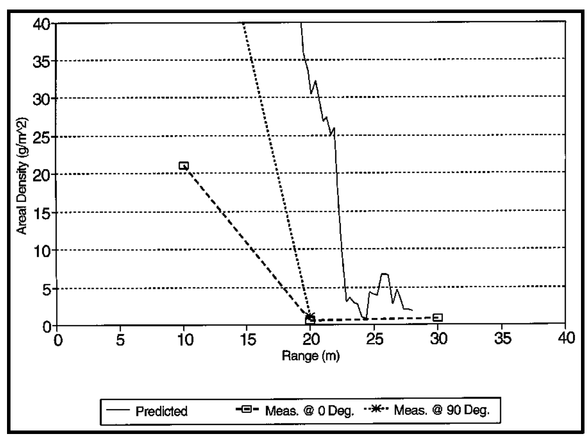

Figure 4. Comparison of Measured and Predicted Areal Debris Densities for Swiss Magazine Test with Loading Density of 0.3 kg/m^3 (Full Scale Charge Weight of 200 kg)

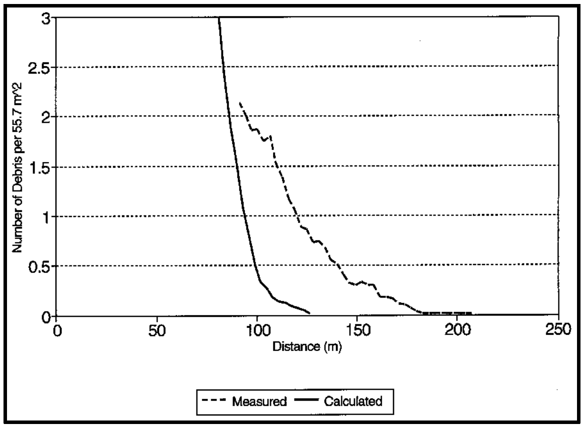

Figure 5. Measured vs. Calculated Debris Density, HAS Test — Side (30 Degree Sector)

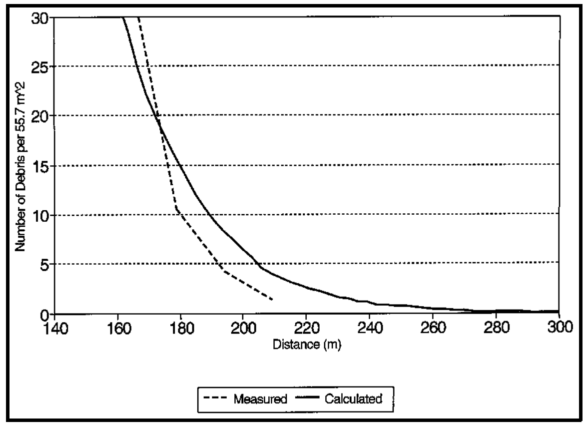

Figure 6. Measured vs. Calculated Debris Density, Distant Runner 4 — Front

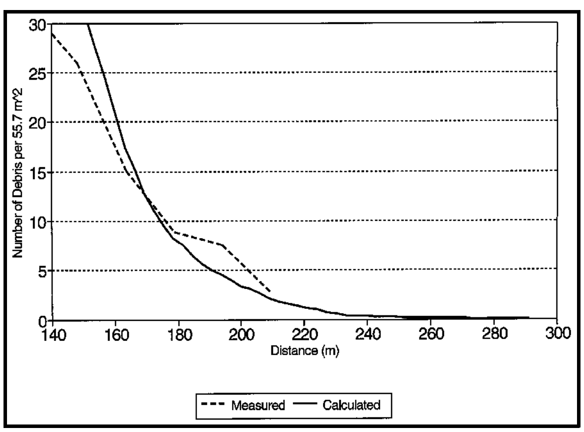

Figure 7. Measured vs. Calculated Debris Density, Distant Runner 4 — Side

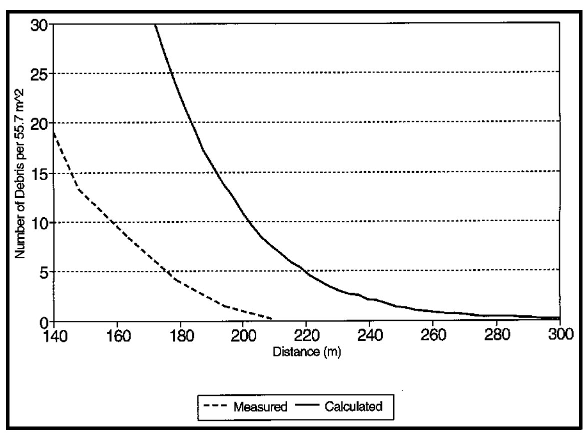

Figure 8. Measured vs. Calculated Debris Density, Distant Runner 4 — Rear

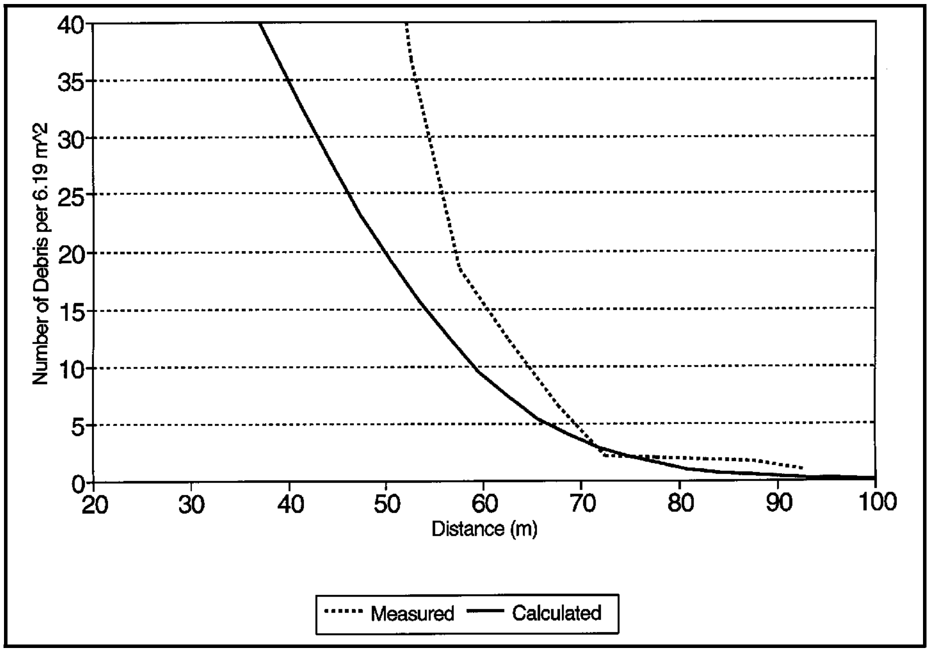

Figure 9. Measured vs. Calculated Debris Density, PAS 3 — Rear

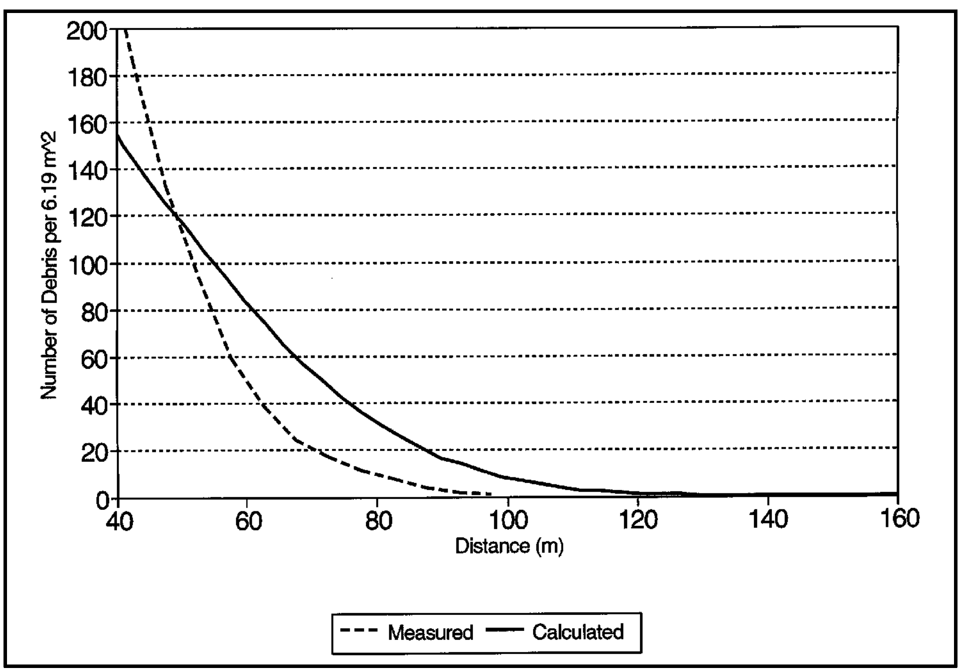

Figure 10. Measured vs. Calculated Debris Density, PAS 5 — Front

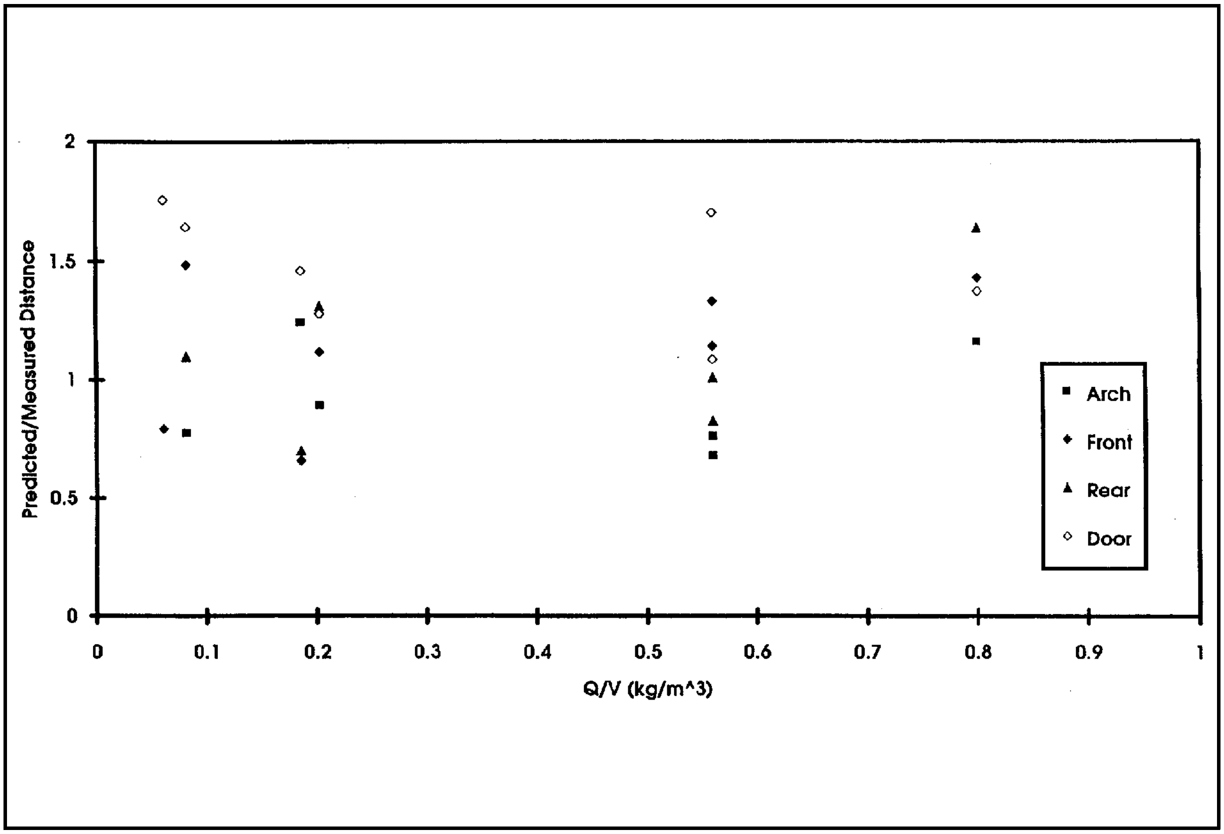

Figure 11. Comparison of Predicted to Measured Hazardous Debris Distances for Aircraft Shelters (DISPRE2, Version 2.0)